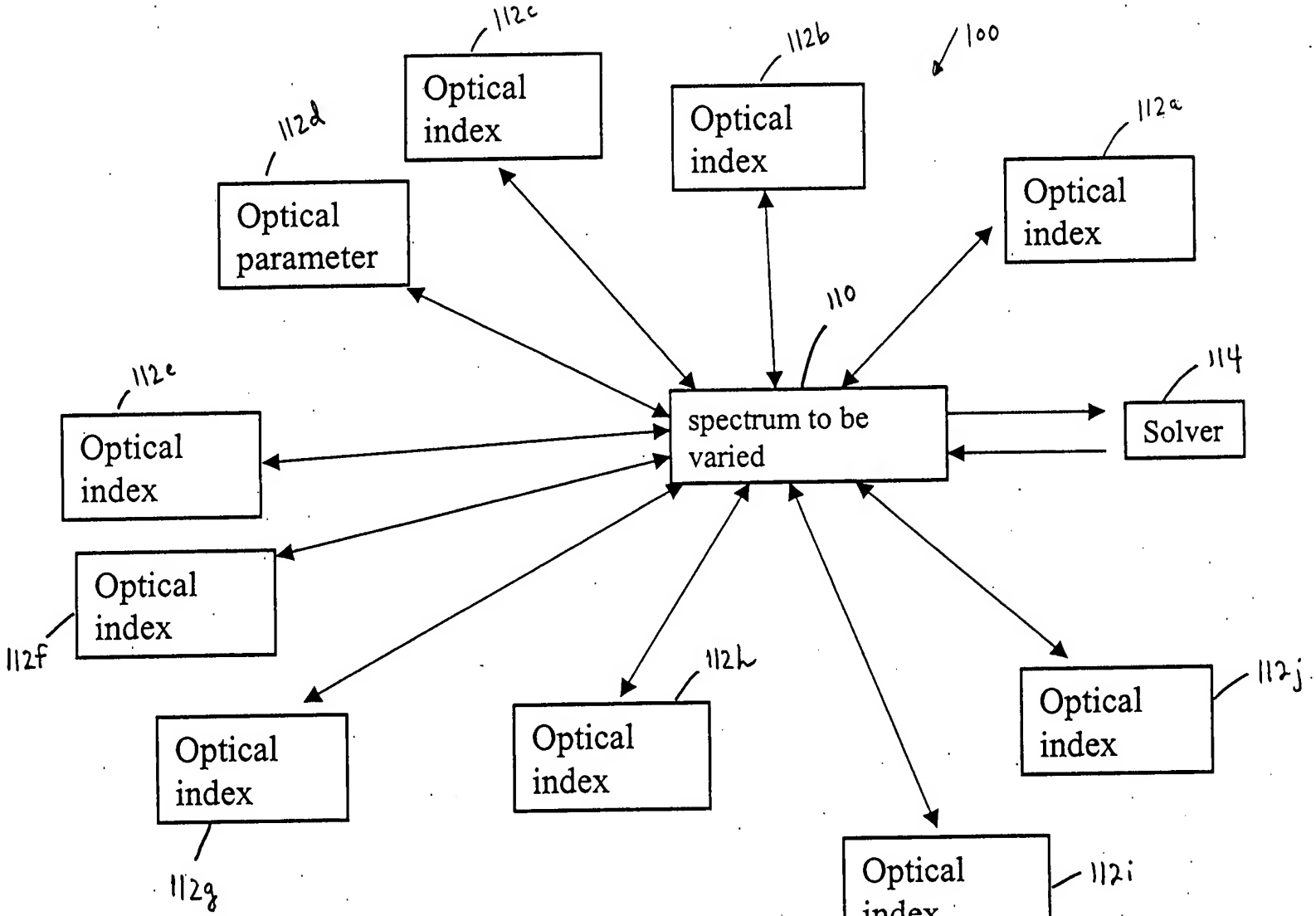

100
110
112a
Optical index
112b
Optical index
112c
Optical index
112d
Optical parameter
112e
Optical index
112f
Optical index
112g
Optical index
112h
Optical index
112i
Optical index
112j
Optical index
114
Solver
spectrum to be varied

FIG. 1

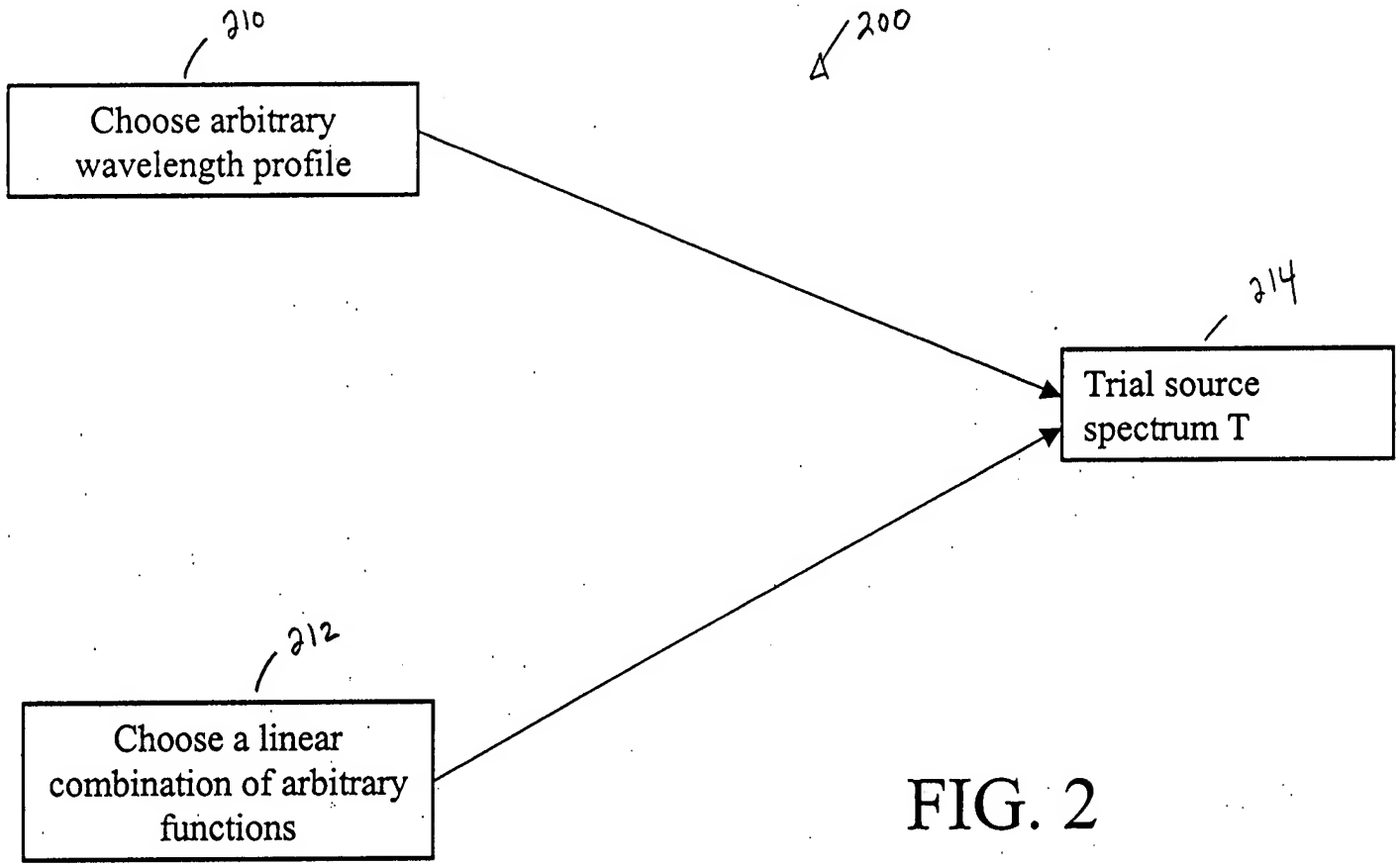

210
200
Choose arbitrary wavelength profile
214
Trial source spectrum T
212
Choose a linear combination of arbitrary functions

FIG. 2

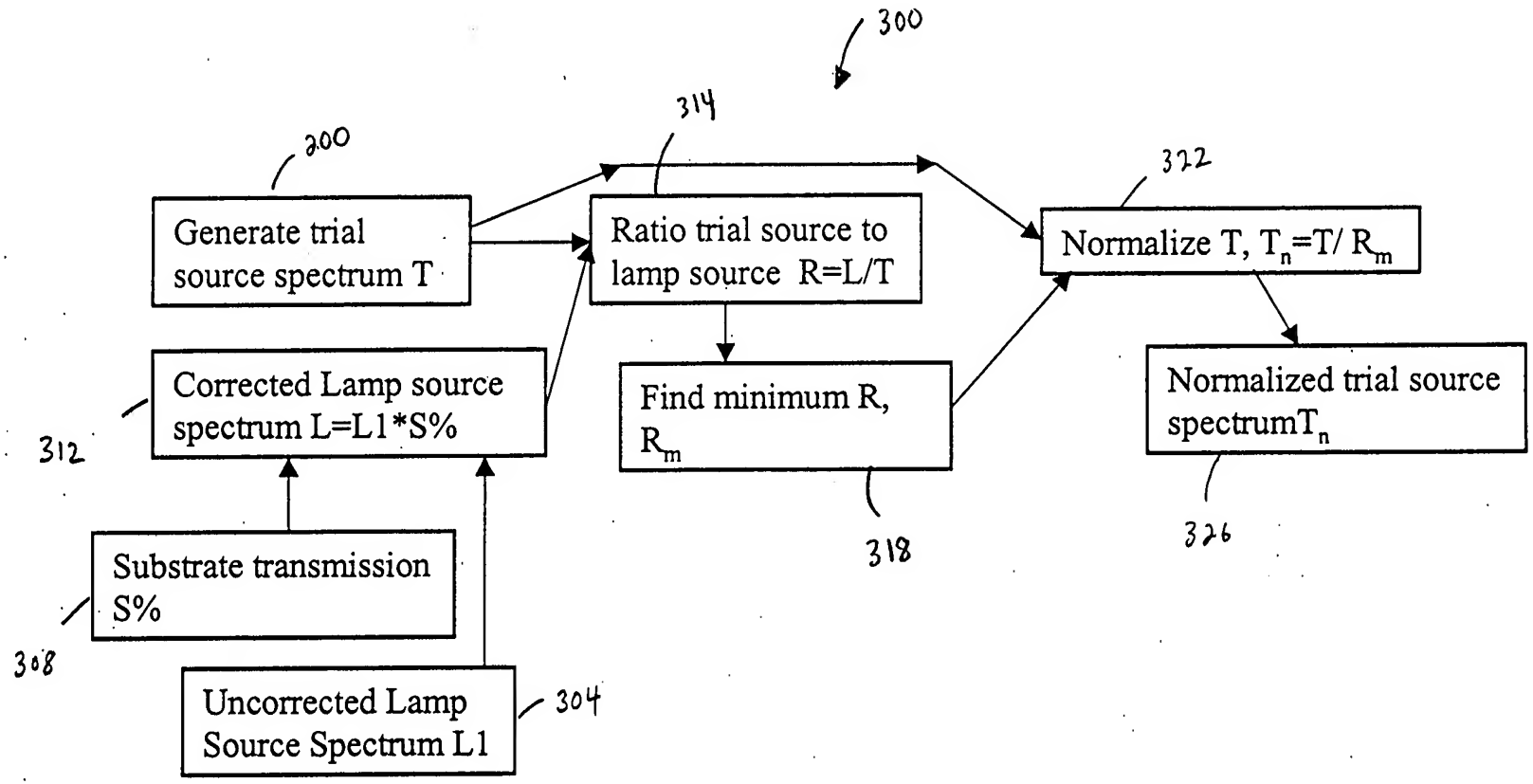

300
200
Generate trial source spectrum T
314
Ratio trial source to lamp source R=L/T
322
Normalize T, T_n=T/ R_m
Corrected Lamp source spectrum L=L1*S%
312
Find minimum R, R_m
318
Normalized trial source spectrumT_n
326
Substrate transmission S%
308
Uncorrected Lamp Source Spectrum L1
304

FIG. 3

FIG. 4

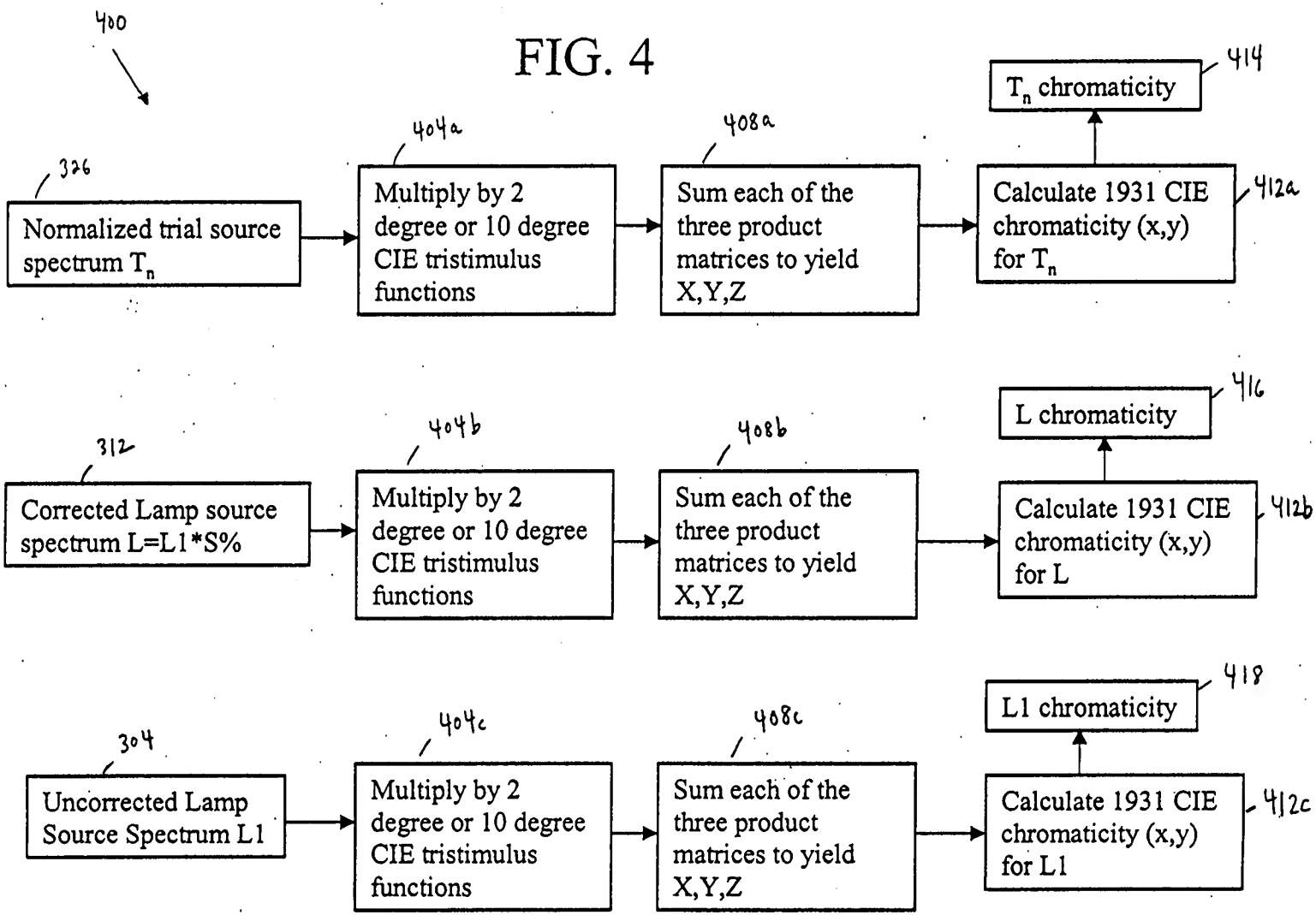
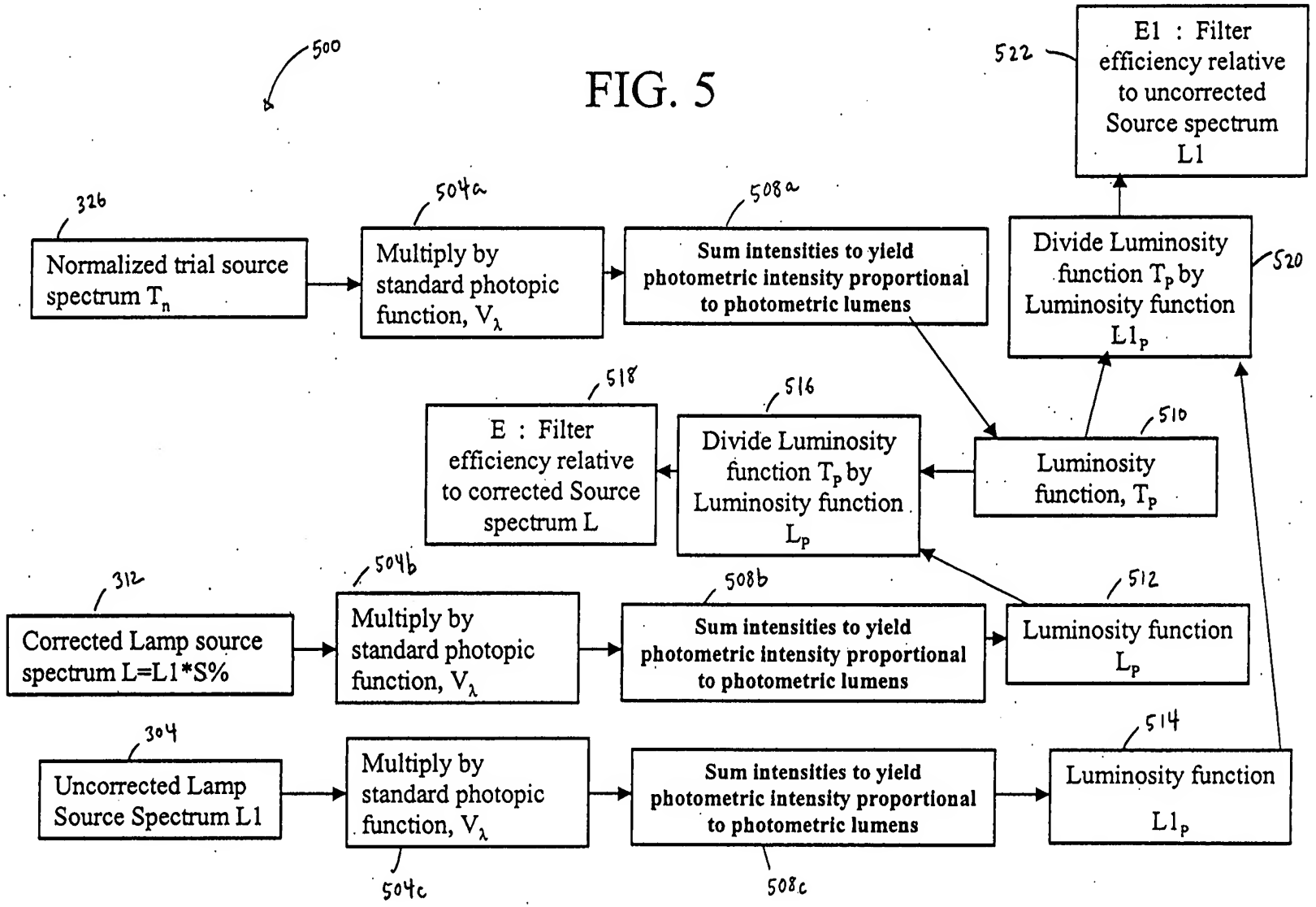

400
326
Normalized trial source spectrum T_n
404a
Multiply by 2 degree or 10 degree CIE tristimulus functions
408a
Sum each of the three product matrices to yield X,Y,Z
Calculate 1931 CIE chromaticity (x,y) for T_n
412a
T_n chromaticity
414
312
Corrected Lamp source spectrum L=L1*S%
404b
Multiply by 2 degree or 10 degree CIE tristimulus functions
408b
Sum each of the three product matrices to yield X,Y,Z
Calculate 1931 CIE chromaticity (x,y) for L
412b
L chromaticity
416
304
Uncorrected Lamp Source Spectrum L1
404c
Multiply by 2 degree or 10 degree CIE tristimulus functions
408c
Sum each of the three product matrices to yield X,Y,Z
Calculate 1931 CIE chromaticity (x,y) for L1
412c
L1 chromaticity
418

FIG. 5


500
326
Normalized trial source spectrum T_n
504a
Multiply by standard photopic function, V_λ
508a
Sum intensities to yield photometric intensity proportional to photometric lumens
522
E1 : Filter efficiency relative to uncorrected Source spectrum L1
520
Divide Luminosity function T_P by Luminosity function $L1_P$
518
E : Filter efficiency relative to corrected Source spectrum L
516
Divide Luminosity function T_P by Luminosity function L_P
510
Luminosity function, T_P
312
Corrected Lamp source spectrum L=L1*S%
504b
Multiply by standard photopic function, V_λ
508b
Sum intensities to yield photometric intensity proportional to photometric lumens
512
Luminosity function L_P
304
Uncorrected Lamp Source Spectrum L1
Multiply by standard photopic function, V_λ
504c
Sum intensities to yield photometric intensity proportional to photometric lumens
508c
514
Luminosity function $L1_P$

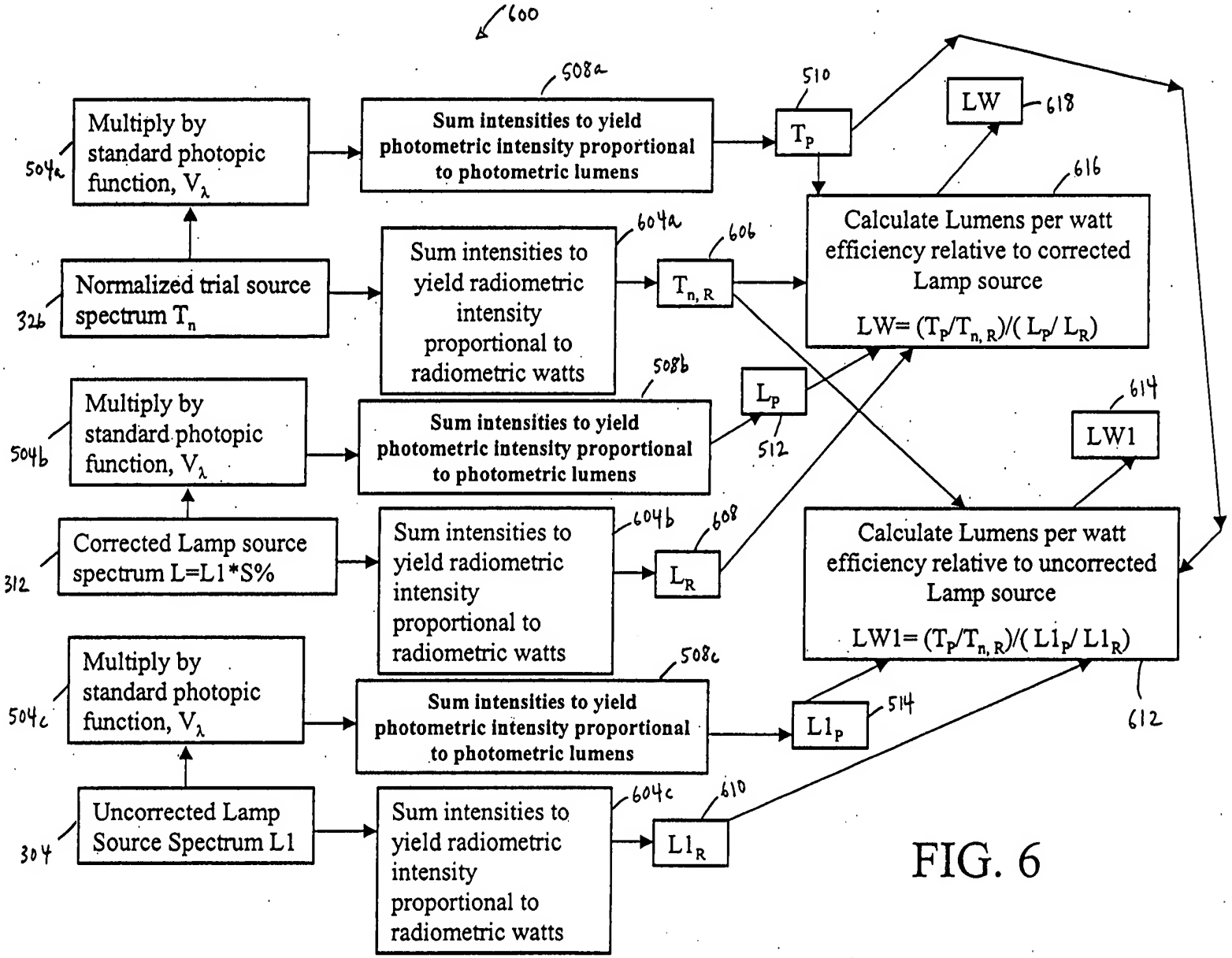

600
Multiply by standard photopic function, V_λ
504a
Sum intensities to yield photometric intensity proportional to photometric lumens
508a
T_P
510
LW
618
Normalized trial source spectrum T_n
326
Sum intensities to yield radiometric intensity proportional to radiometric watts
604a
$T_{n,R}$
606
Calculate Lumens per watt efficiency relative to corrected Lamp source
$LW = (T_P/T_{n,R})/(L_P/L_R)$
616
Multiply by standard photopic function, V_λ
504b
Sum intensities to yield photometric intensity proportional to photometric lumens
508b
L_P
512
LW1
614
Corrected Lamp source spectrum L=L1*S%
312
Sum intensities to yield radiometric intensity proportional to radiometric watts
604b
L_R
608
Calculate Lumens per watt efficiency relative to uncorrected Lamp source
$LW1 = (T_P/T_{n,R})/(L1_P/L1_R)$
612
Multiply by standard photopic function, V_λ
504c
Sum intensities to yield photometric intensity proportional to photometric lumens
508c
$L1_P$
514
Uncorrected Lamp Source Spectrum L1
304
Sum intensities to yield radiometric intensity proportional to radiometric watts
604c
$L1_R$
610

FIG. 6

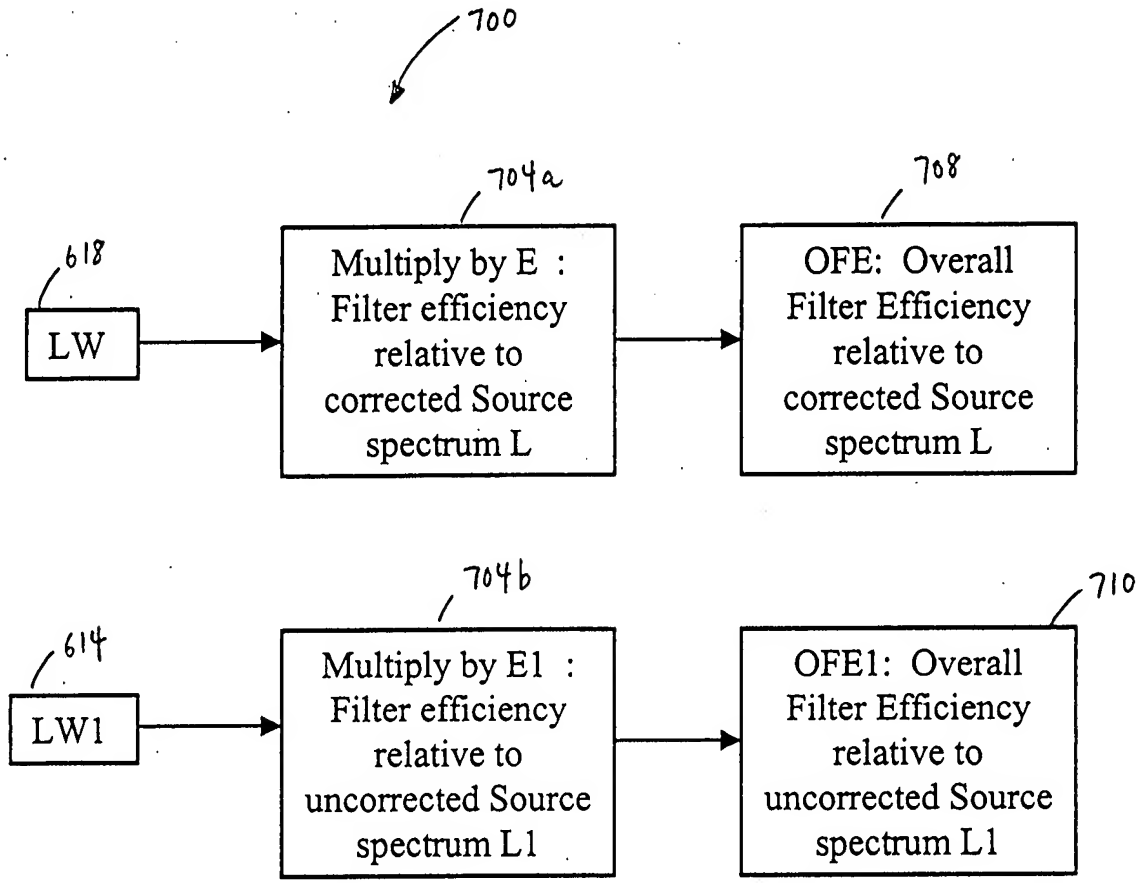

700
704a
708
618
LW
Multiply by E : Filter efficiency relative to corrected Source spectrum L
OFE: Overall Filter Efficiency relative to corrected Source spectrum L
704b
710
614
LW1
Multiply by E1 : Filter efficiency relative to uncorrected Source spectrum L1
OFE1: Overall Filter Efficiency relative to uncorrected Source spectrum L1

FIG. 7

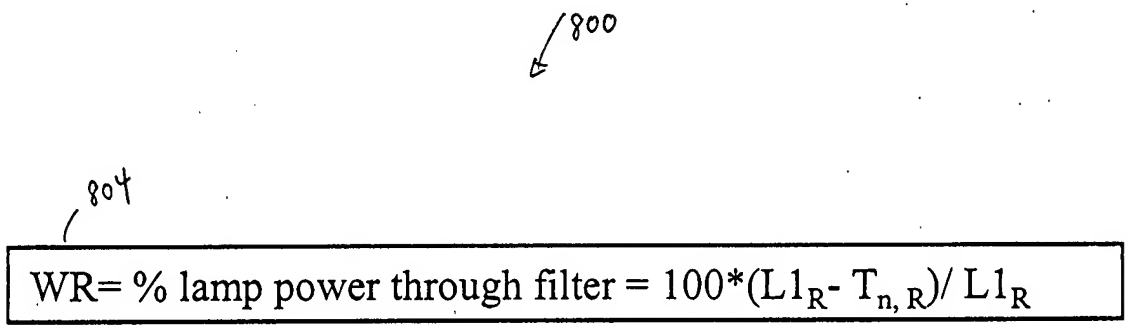


FIG. 8

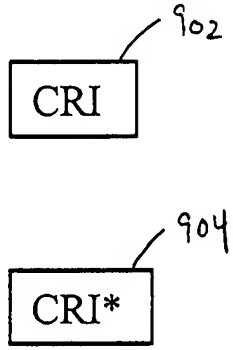


FIG. 9A

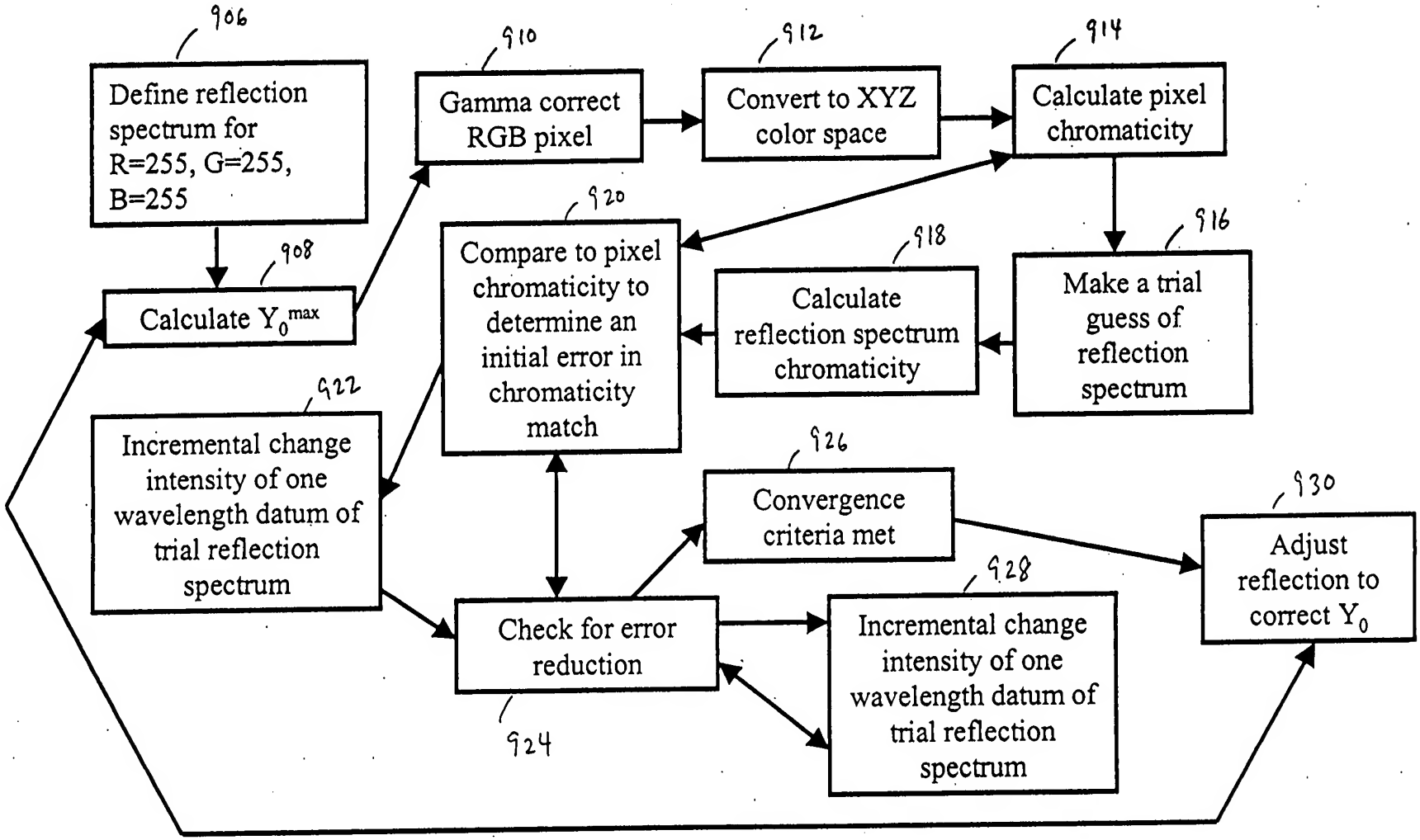

906
Define reflection spectrum for R=255, G=255, B=255
908
Calculate Y_0^{max}
910
Gamma correct RGB pixel
912
Convert to XYZ color space
914
Calculate pixel chromaticity
916
Make a trial guess of reflection spectrum
918
Calculate reflection spectrum chromaticity
920
Compare to pixel chromaticity to determine an initial error in chromaticity match
922
Incremental change intensity of one wavelength datum of trial reflection spectrum
924
Check for error reduction
926
Convergence criteria met
928
Incremental change intensity of one wavelength datum of trial reflection spectrum
930
Adjust reflection to correct Y_0

FIG. 9B

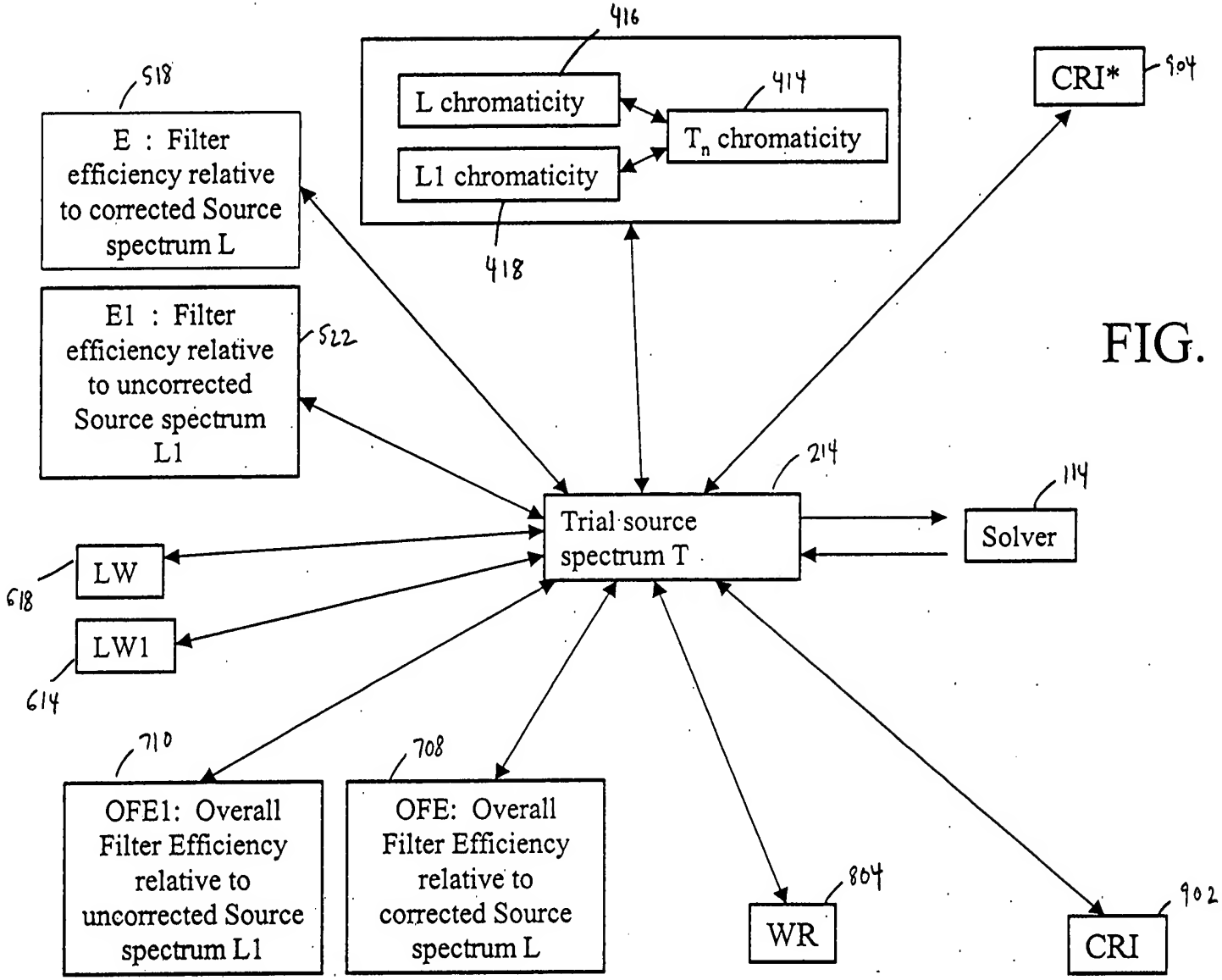

416
L chromaticity
414
T_n chromaticity
L1 chromaticity
418
518
E : Filter efficiency relative to corrected Source spectrum L
522
E1 : Filter efficiency relative to uncorrected Source spectrum L1
CRI*
904
214
Trial source spectrum T
114
Solver
618
LW
614
LW1
710
OFE1: Overall Filter Efficiency relative to uncorrected Source spectrum L1
708
OFE: Overall Filter Efficiency relative to corrected Source spectrum L
804
WR
902
CRI

FIG. 10

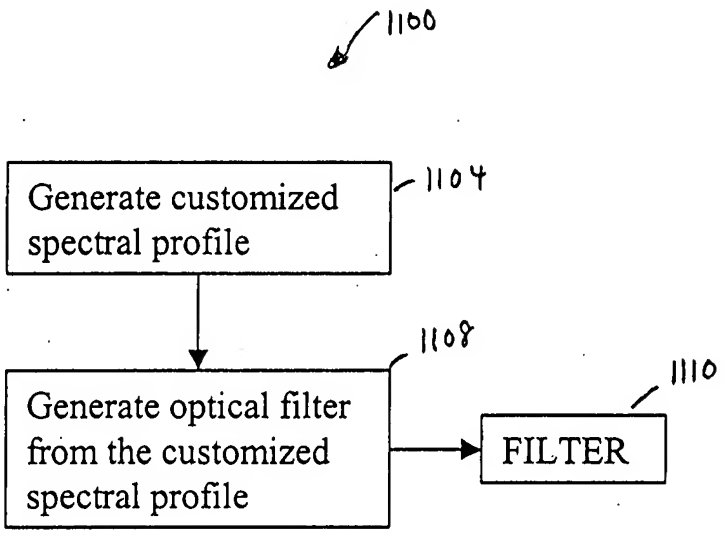

1100
Generate customized spectral profile
1104
Generate optical filter from the customized spectral profile
1108
FILTER
1110

FIG. 11

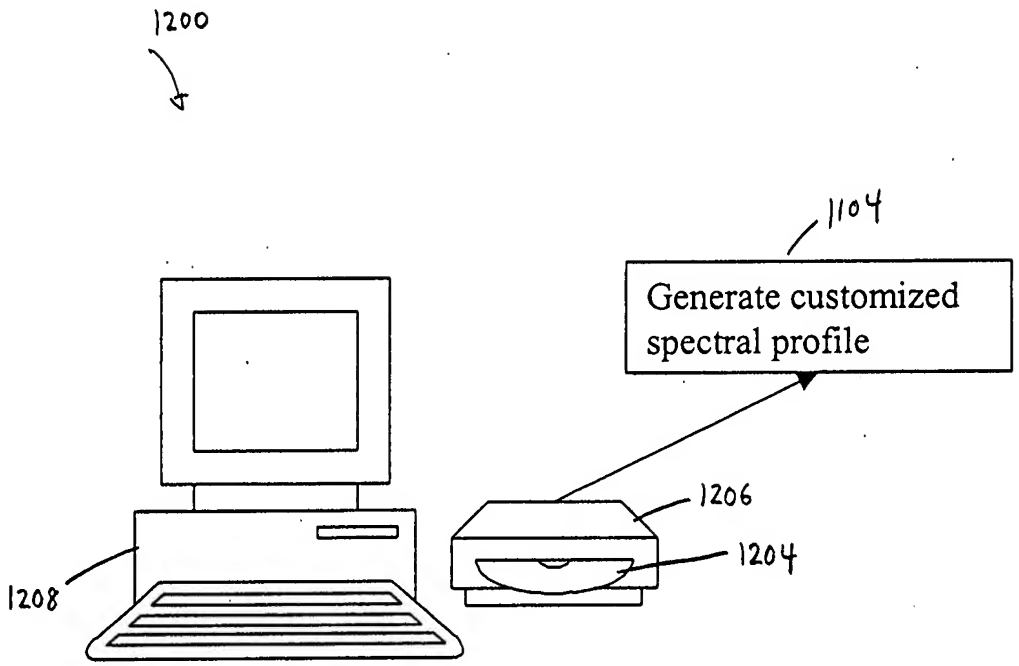

1200
1104
Generate customized spectral profile
1206
1204
1208

FIG. 12

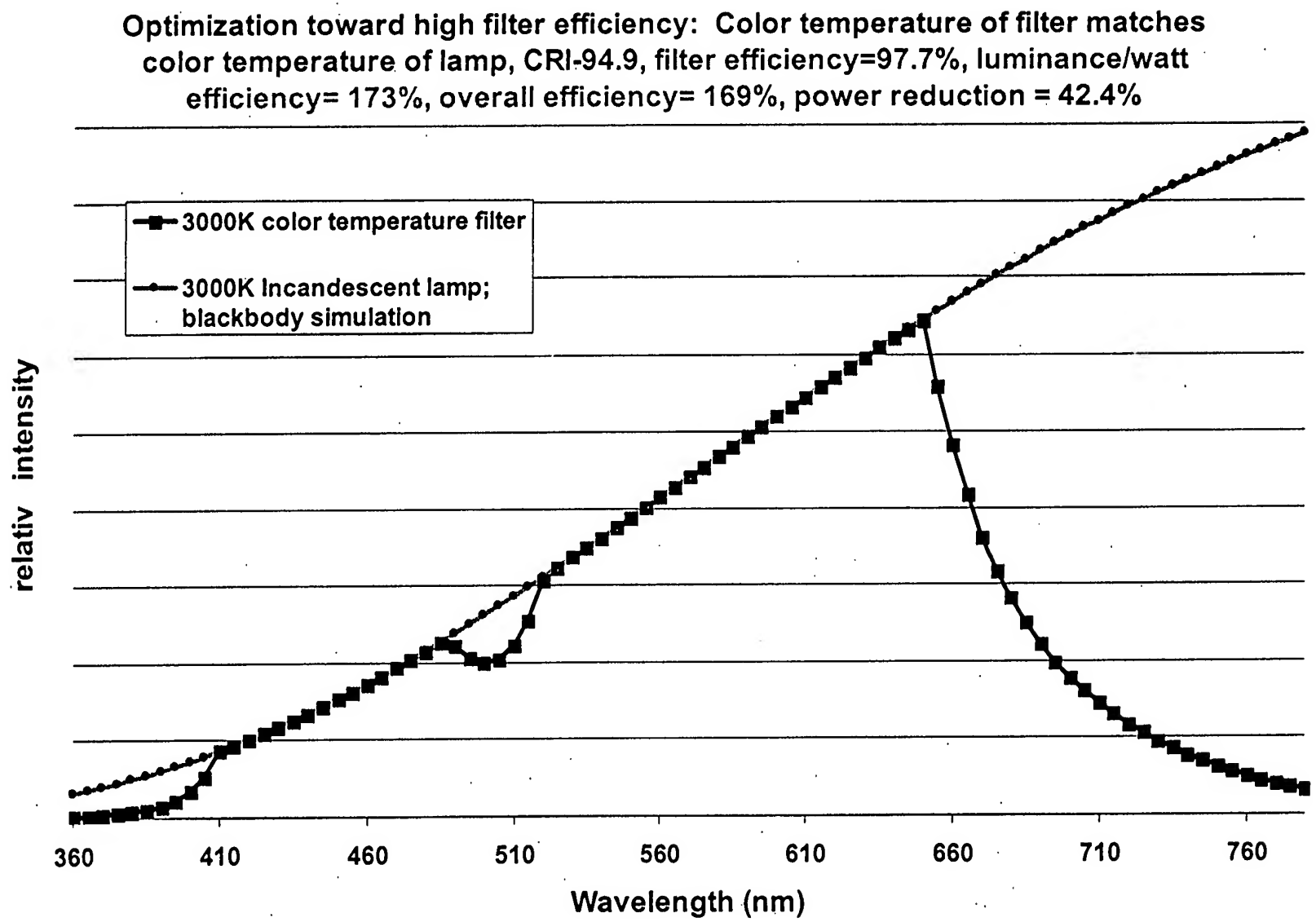

Optimization toward high filter efficiency: Color temperature of filter matches color temperature of lamp, CRI-94.9, filter efficiency=97.7%, luminance/watt efficiency= 173%, overall efficiency= 169%, power reduction = 42.4%
3000K color temperature filter
3000K Incandescent lamp; blackbody simulation
relativ intensity
360
410
460
510
560
610
660
710
760
Wavelength (nm)

FIG. 13

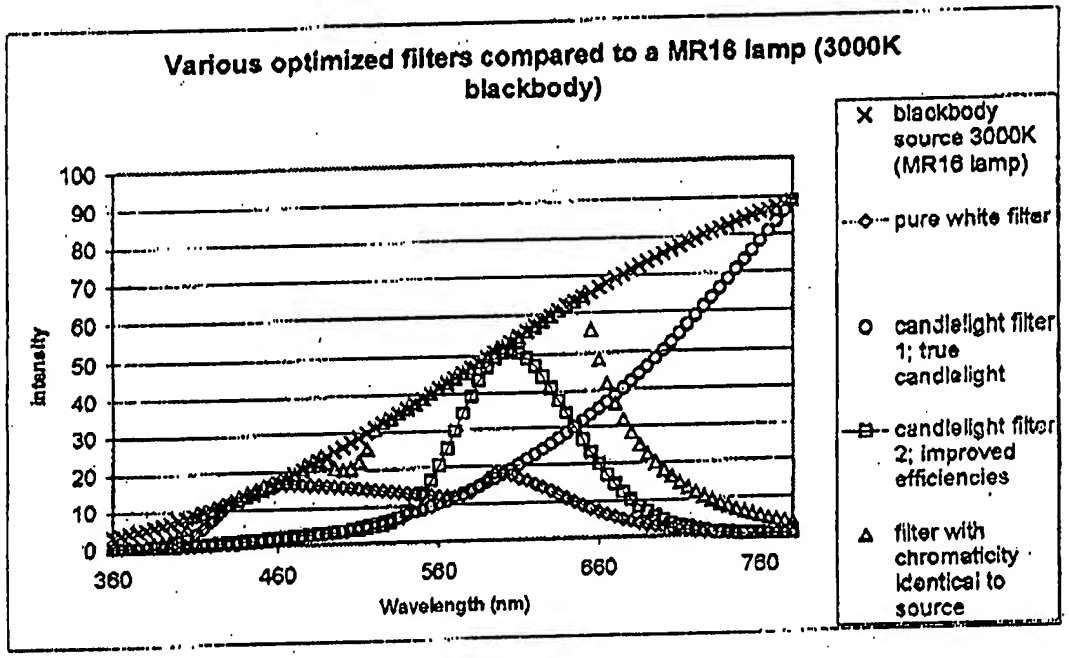

Various optimized filters compared to a MR16 lamp (3000K blackbody)
Intensity
100
90
80
70
60
50
40
30
20
10
0
360
460
560
660
760
Wavelength (nm)
blackbody source 3000K (MR16 lamp)
pure white filter
candlelight filter 1; true candlelight
candlelight filter 2; improved efficiencies
filter with chromaticity identical to source

FIG. 14

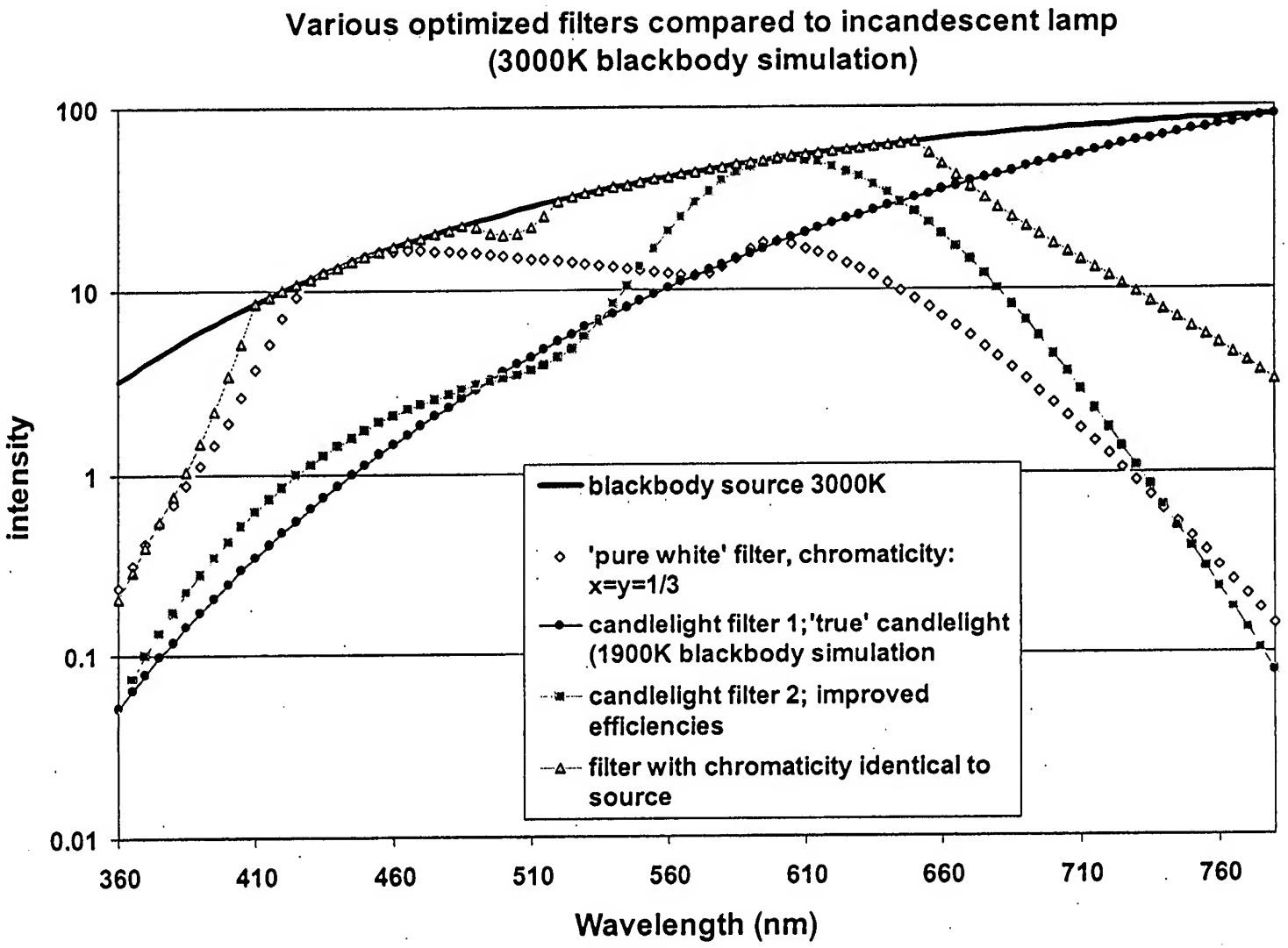

Various optimized filters compared to incandescent lamp
(3000K blackbody simulation)
100
10
1
0.1
0.01
intensity
360
410
460
510
560
610
660
710
760
Wavelength (nm)
blackbody source 3000K
'pure white' filter, chromaticity: x=y=1/3
candlelight filter 1;'true' candlelight (1900K blackbody simulation
candlelight filter 2; improved efficiencies
filter with chromaticity identical to source

FIG. 15

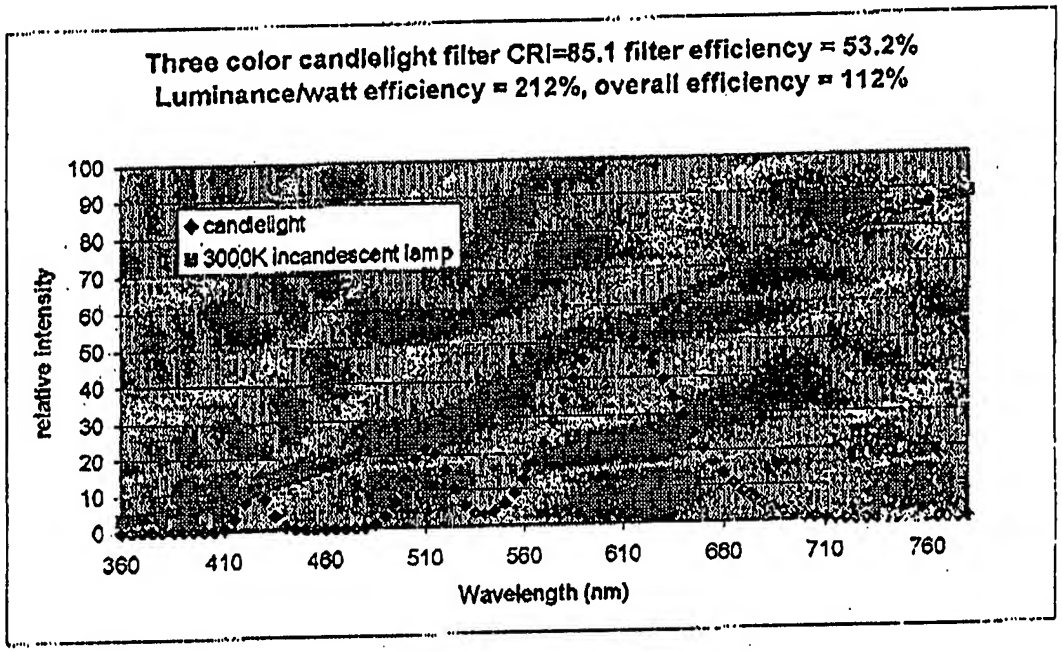

Three color candlelight filter CRI=85.1 filter efficiency = 53.2%
Luminance/watt efficiency = 212%, overall efficiency = 112%
candlelight
3000K incandescent lamp
relative intensity
100
90
80
70
60
50
40
30
20
10
0
360
410
460
510
560
610
660
710
760
Wavelength (nm)

FIG. 16

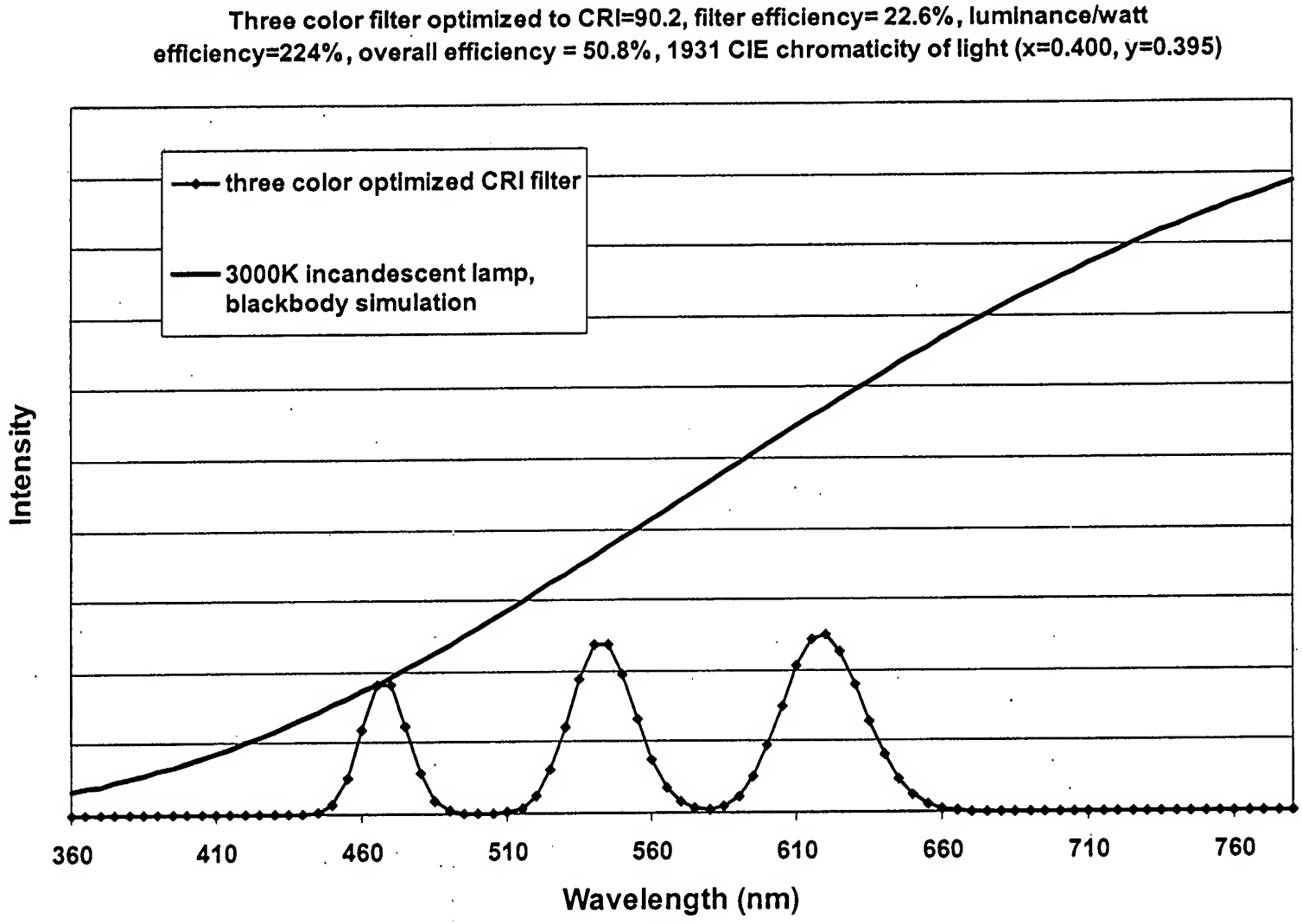

Three color filter optimized to CRI=90.2, filter efficiency= 22.6%, luminance/watt efficiency=224%, overall efficiency = 50.8%, 1931 CIE chromaticity of light (x=0.400, y=0.395)
three color optimized CRI filter
3000K incandescent lamp, blackbody simulation
Intensity
360
410
460
510
560
610
660
710
760
Wavelength (nm)

FIG. 17

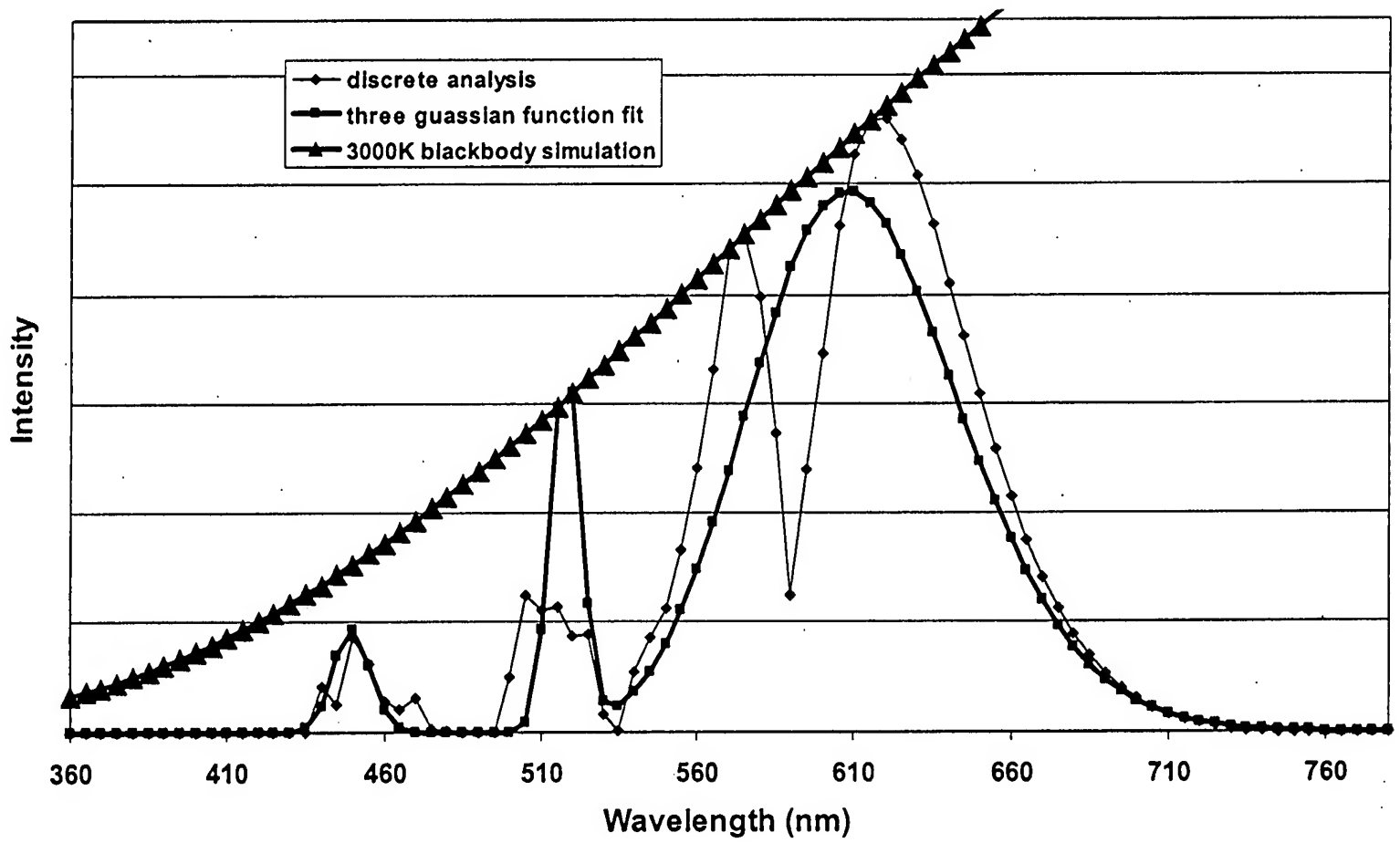

Monet, La maison vue du jardin aux Roses, Musée Marmottan, Paris
(left eye painting, 1925), three-Gaussian and discrete fits
discrete analysis
three guassian function fit
3000K blackbody simulation
Intensity
360
410
460
510
560
610
660
710
760
Wavelength (nm)

FIG. 18

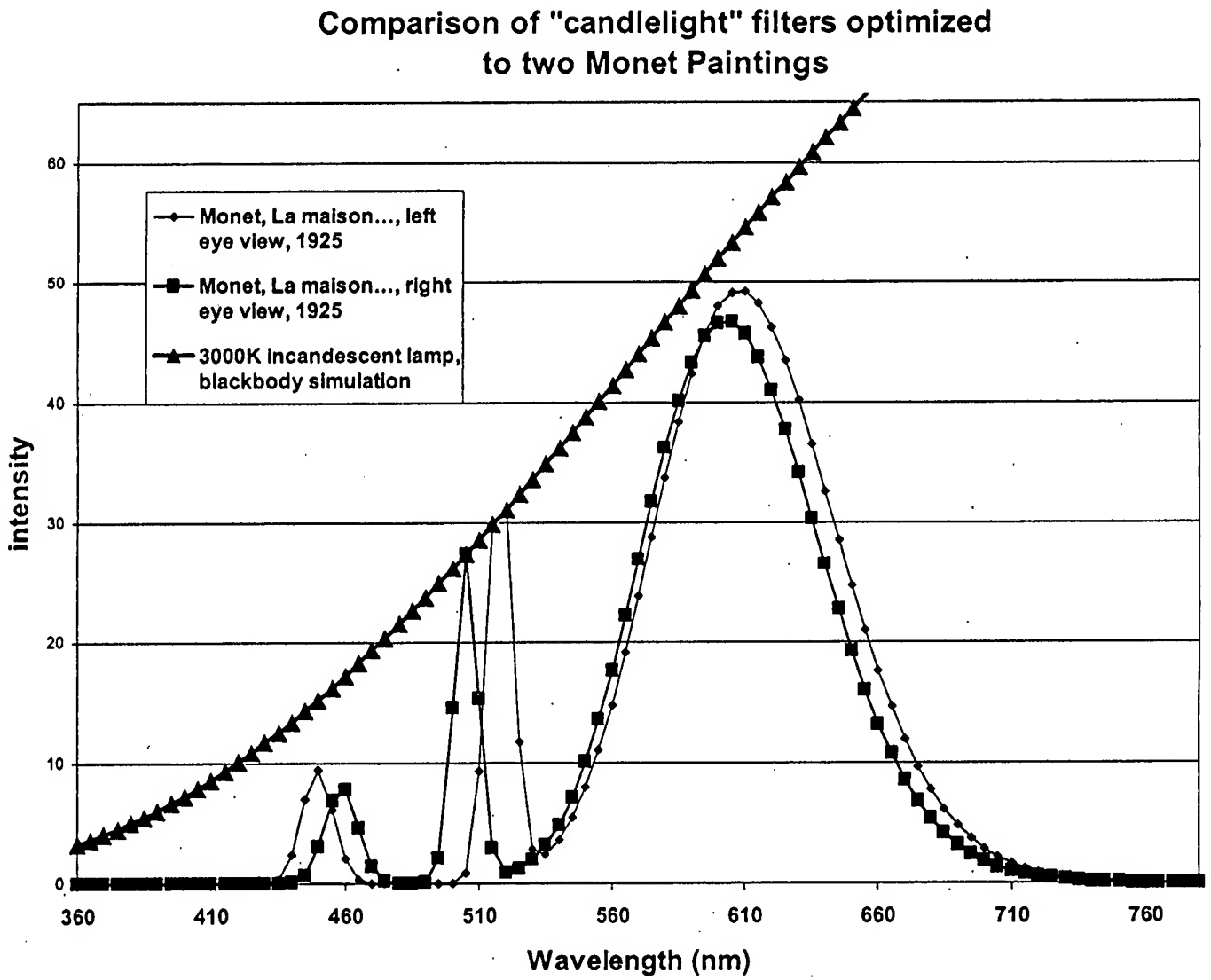

Comparison of "candlelight" filters optimized to two Monet Paintings
Monet, La maison..., left eye view, 1925
Monet, La maison..., right eye view, 1925
3000K incandescent lamp, blackbody simulation
intensity
0
10
20
30
40
50
60
360
410
460
510
560
610
660
710
760
Wavelength (nm)

FIG. 19

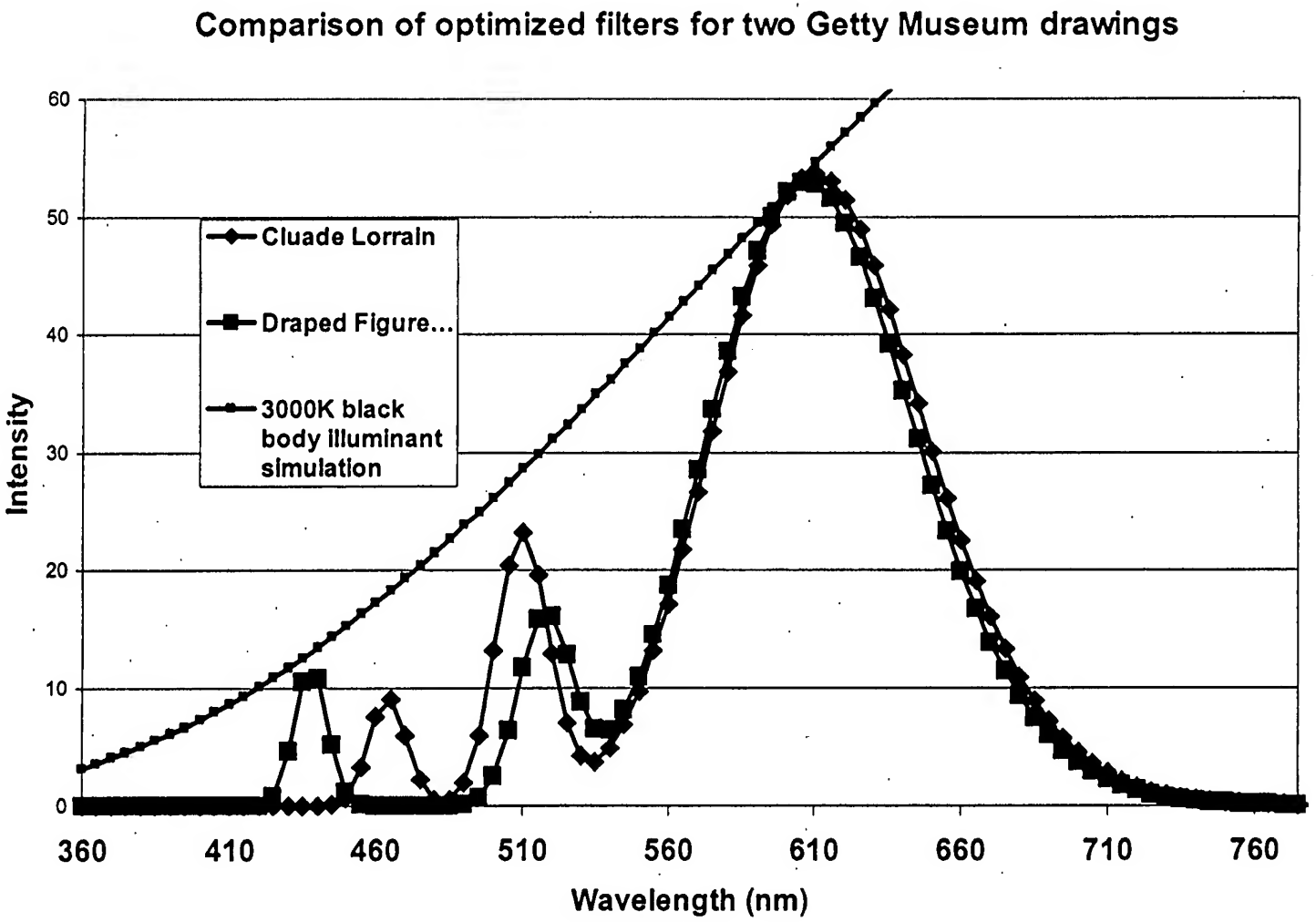

Comparison of optimized filters for two Getty Museum drawings
Cluade Lorrain
Draped Figure...
3000K black body illuminant simulation
Intensity
Wavelength (nm)
0
10
20
30
40
50
60
360
410
460
510
560
610
660
710
760

FIG. 20

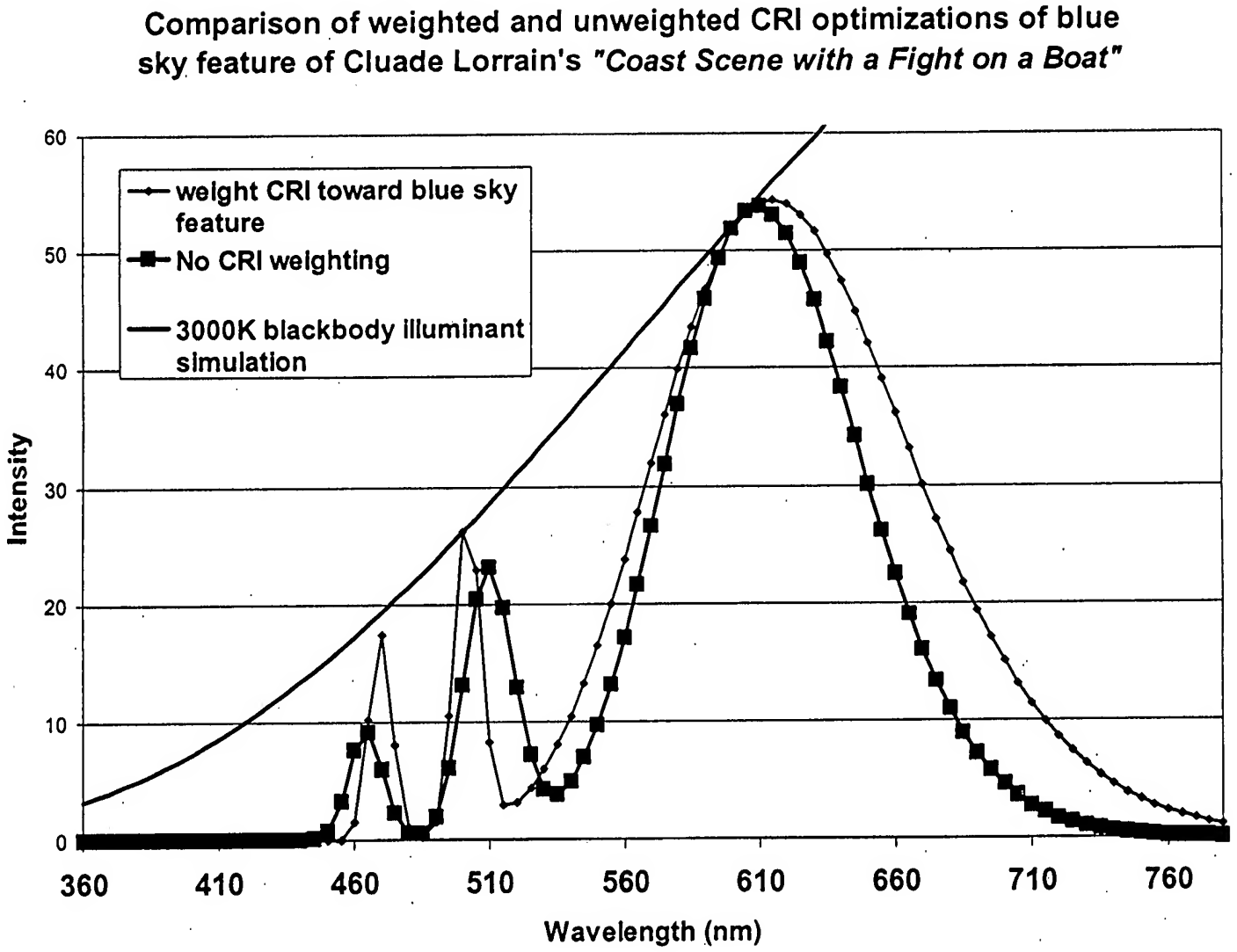

Comparison of weighted and unweighted CRI optimizations of blue sky feature of Cluade Lorrain's "Coast Scene with a Fight on a Boat"
weight CRI toward blue sky feature
No CRI weighting
3000K blackbody illuminant simulation
Intensity
Wavelength (nm)
0
10
20
30
40
50
60
360
410
460
510
560
610
660
710
760

FIG. 21

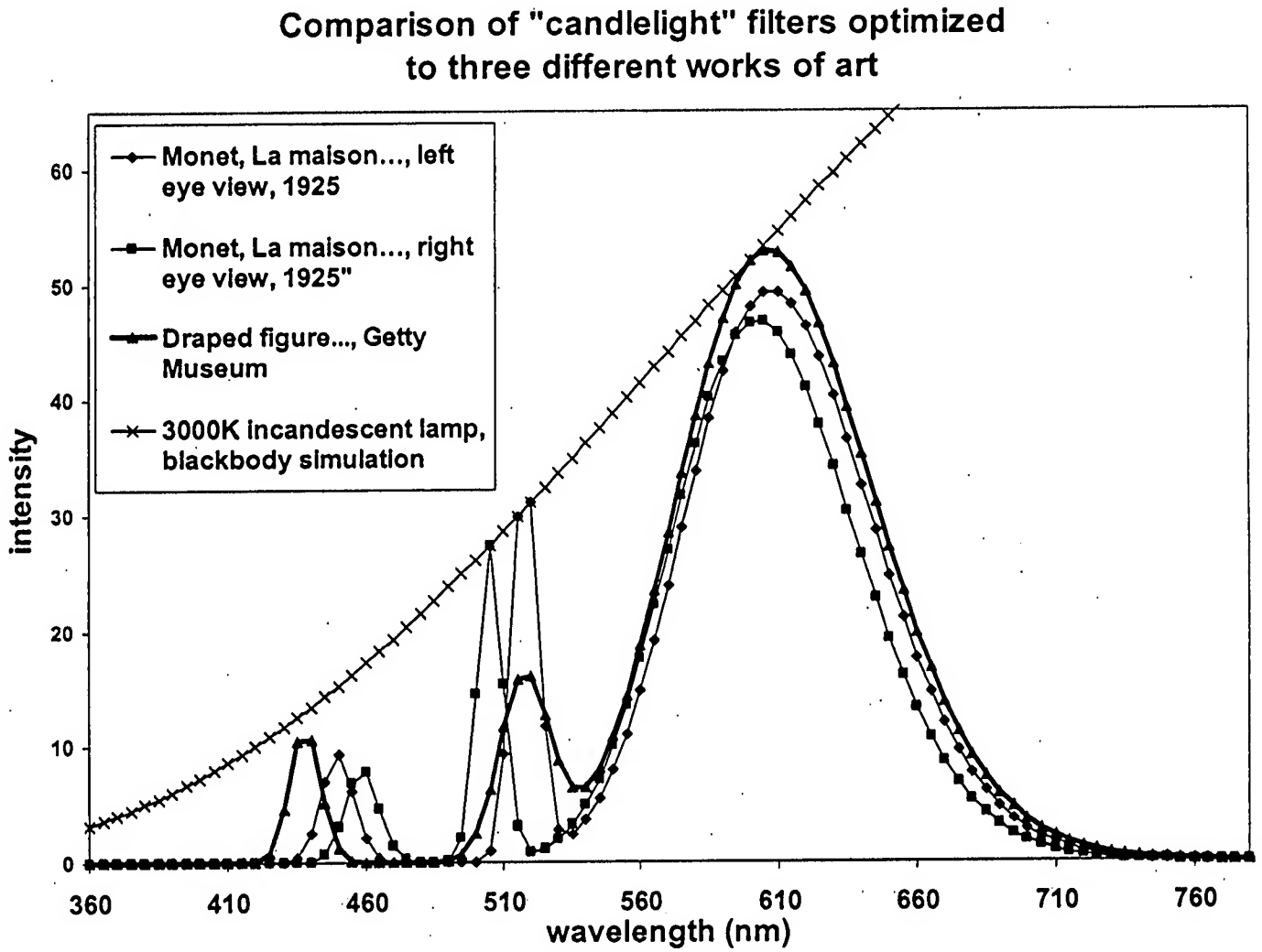

Comparison of "candlelight" filters optimized to three different works of art
Monet, La maison..., left eye view, 1925
Monet, La maison..., right eye view, 1925"
Draped figure..., Getty Museum
3000K incandescent lamp, blackbody simulation
intensity
0
10
20
30
40
50
60
360
410
460
510
560
610
660
710
760
wavelength (nm)

FIG. 22